

# Experimental Study of Thermal Properties of Aluminum Matrix Composites Inserted Multiwalled Carbon Nanotubes for Heat Sink Applications

<sup>1</sup>\*I Dewa Made Pancarana, <sup>2</sup>I Nyoman Budiartana

<sup>1,2</sup>Mechanical Engineering Department, Bali State Polytechnic, Bali, Indonesia. 80364

\*Corresponding Author's E-mail: [dmpancarana@yahoo.com](mailto:dmpancarana@yahoo.com)

**Abstract** - The heat sink is an important component in laptop computers as it dissipates the heat generated by the system. The efficiency, cost and overall size of the system can be affected by the heat sink device. Four selection criteria; thermal conductivity, coefficient of thermal expansion, density and minimal cost to choose a laptop computer cooling material. The ideal heat sink material exhibits high thermal conductivity, low coefficient of thermal expansion, low density and low cost. In this study, we investigated the thermal properties of aluminum matrix composites reinforced with 0-10 wt% copper-coated Multiwalled carbon nanotubes (MWNTs) produced by liquid state processing. Composites with the addition of <10 wt.% MWNTs have higher thermal conductivity than pure aluminum produced by the same liquid state processing. The MWNTs/Al composite exhibited a maximum thermal conductivity of 199 W/m/K at 5 wt.% MWNTs. The increase in thermal conductivity is supported by the measured micro hardness. The MWNTs/Al composites exhibited a maximum microhardness of 90 HV also at 5 wt.% MWNTs. The contribution of carbon nanotubes to the thermal conductivity of the composite was demonstrated by theoretical analysis. The results showed that MWNT-reinforced aluminum matrix composite is a potential material for high thermal conductivity applications, such as heat sink applications.

**Keywords:** heat sink, thermal conductivity, composites, aluminum, multi-walled carbon nanotubes.

## I. INTRODUCTION

The expansion in heat from electronic parts is a significant issue looked in electronic innovation due to the scaling down of these parts [1-3]. Heat sinks are utilized to scatter the intensity produced by these electronic parts. An intensity sink is portrayed as an item that scatters or disseminates heat from another article. Typically heat sinks are generally utilized in PCs and microelectronics as well as different applications [4, 5].

In PCs, an intensity sink is connected to the chip to assist with keeping the chip from overheating. Hartle [5], states that PC coolers are thermal guides that divert heat from the PC's focal handling unit (central processor) as blades that give an enormous surface region to scattering intensity to different pieces of the PC. With the rising pace of processors and the scaling down of PC computer chips, heat sinks have become extremely essential as frameworks will generally overheat without a cooling system.

Metal materials are normally used to create heat sinks that capability as intensity conveyors that eliminate heat from the computer processor. Notwithstanding, there are benefits and burdens of various metal materials utilized for the development of intensity sinks. The thermal conductivity of metallic materials is an issue that should be thought of. The higher the thermal conductivity of the metal material, the better in dispersing heat.

Aluminum is the most normally involved material for heat sinks because of its light weight, lower cost, fabricating capacity, and foundation [6]. The thermal conductivity of aluminum is around 220 W/mK [7-10]. The higher this number the more intensity the material can lead. Also, copper can be utilized for the development of intensity sinks in light of its high thermal conductivity worth of around 400 W/mK [7]. Its principal detriment over aluminum is that it is multiple times heavier and more costly.

Materials with high thermal conductivity (TC) and low coefficient of thermal development (CTE) are the decision for PC sinks. A material reasonable for this reason should join two fundamental properties: it should have a high thermal conductivity (TC) and an appropriate coefficient of thermal development (CTE) (like semiconductors utilized in the production of electronic circuits). Likewise, for every specific application, other extra properties might be required: high substance latency, erosion obstruction, wear opposition, and so on.

Carbon nanotubes (CNTs) with exceptional mechanical properties, extremely low thermal extension ( $CTE \approx 0$ ), and high thermal conductivity [11-13], are potential support materials for use in composites. As indicated by hypothetical forecasts and exploratory estimations, the thermal conductivity of CNTs comes to as high as 3000-6600 W/m/K [14,15]. Aluminum is one of the main matrix materials for MMC. The mechanical properties of CNT-built up Al framework composites (CNT/Al composites) have been concentrated seriously.

Up to this point, a couple of studies have examined the thermal conduction conduct of CNT/Al composites. Bakshi, et al., [16] delivered a composite of 10 wt.% CNTs/Al utilizing plasma splashing and the thermal conductivity was just 25.4 W/m/K, significantly less than unadulterated Al. Yamanaka et al. Yamanaka, et al., [17], revealed that the thermal conductivity of CNTs/Al composites diminished with expanding CNT content. The revealed thermal conductivity for CNTs/Cu composites [18,19], likewise showed a diminishing pattern contrasted with unadulterated Cu. The reduction in thermal conductivity was for the most part connected with the agglomeration of CNTs which brought about the thermal opposition of the connection point into the composite. Two necessities should be met to: accomplish high thermal conductivity in the CNT/metal composite - the composite has low interfacial thermal obstruction and the CNT is homogeneously scattered in the metal matrix.

This research focuses on the thermal conduction behavior of aluminum matrix composites reinforced with multiwall nanotubes (MWNTs/Al composites) produced by the stir casting process. Stir casting processing is a very useful technique for bonding non-sinterable materials such as carbon nanotubes. In order to produce a homogeneous dispersion of carbon nanotubes in an aluminum matrix, the powdered carbon nanotubes were first modified before being incorporated into the aluminum melt.

## II. MATERIALS AND EXPERIMENTALS PROCEDURES

### 2.1 Materials

Multiwalled carbon nanotubes provided by Chengdu Natural Synthetic substances Co. Ltd., China (OD: 10 - 20 nm, length: 10 - 30 m and immaculateness > 98% ) were utilized in the current review. The colloidal palladium-tin activator made with a creation of 0.5 g palladium chloride ( $PdCl_2$ ), 50 ml 37% hydrochloride corrosive (HCl), 200 ml deionised water, 25 g stannous chloride. Cupric Sulfate Pentahydrate (98.5% Measure) and Sodium Carbonate Anhydrous (99.5% Examine) were provided by Bofa Laboratotium. Sodium Hydroxide (close to 100% Examine) was provided by Bofa Laboratotium.

Pottasium Sodium Tartrate Tetrahydrate or what is known as Rochelle salt (close to 100% Examine) was provided by Bofa Laboratotium. Cobalt (II) Chloride Hexahydrate (almost 100% Examine) was provided by Bofa Laboratotium. Formaldehyde 37% in watery arrangement was provided by Bofa Laboratotium.

### 2.2 Experimental Procedures

The metallization of CNTs by copper was led in three stages. The interaction began by the enactment of CNTs surface utilizing colloidal Pd-Sn particles followed by the speed increase move toward eliminate stannous hydroxide stores on top of the actuated surface. At last, the electroless plating of Cu-Co on top of CNTs was preceded as displayed Figure 1.

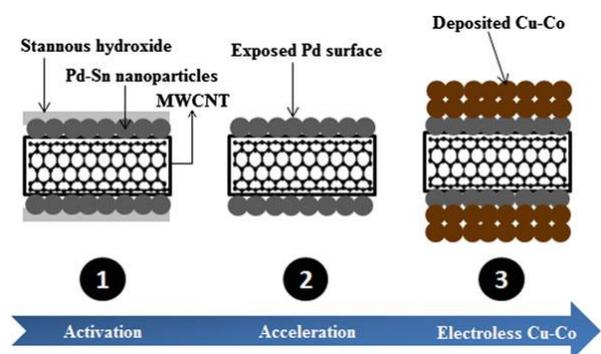


Figure 1: General scheme of Cu-Co electroless plating on CNTs

#### 2.2.1 Activation of CNT's in Pd-Sn Colloidal Solution

How much CNTs utilized in this cycle was fixed to 0.1 gm of MWCNTs. The CNTs were utilized as gotten with no functionalization. The CNTs were initiated utilizing a colloidal Pd-Sn arrangement adjusted from the Plating on Plastics (POP) industry. The enactment cycle was finished in a combination of 37,5 ml colloidal Pd-Sn arrangement, 37,5 ml HCl (37 %), and 175 ml DI water. While utilizing, blend 15% palladium-tin colloid impetus arrangement and 15% hydrochloride corrosive (37%) together, and balance with deionised water, then warmed to a temperature of 50 - 60 °C to get a superior reactant impact.

For the actuation, the CNTs were scattered by attractive stirrer in the colloidal answer for 30 minutes. When the blending was finished, the treated CNTs were filtered out utilizing 0.22 1 m PTFE filter film on a microfiltration unit. After filtration, CNTs were redispersed in water and refiltered again to eliminate the overabundance colloidal particles and hints of the colloidal arrangement from the enacted Cnt's. After the filtration, CNTs were gathered from the film utilizing tweezers.

### 2.2.2 Acceleration of CNTs in a Mixture of Acids

The CNTs were then positioned in an answer of a combination of acids known as the gas pedal. The capability of the gas pedal is to eliminate abundance tin hydroxide from the outer layer of the synergist particles on CNTs permitting the palladium surface to be uncovered. It was surmised that the speed increase doesn't eliminate tin from the center of the colloidal particles [20]. The speed increase process utilizes HF corrosive 55% (50 mL) in 500 mL DI water.

After speed increase, the CNTs were redispersed in water and filtered again to eliminate the hints of the past arrangement. By following the past advances, the outer layer of CNTs was delivered synergist.

### 2.2.3 Electroless Cu-Co Plating of CNTs

A 1-liter arrangement of the Cu-Co electrolyte was arranged involving the focuses in Table 1.

Table 1: Typical concentrations of Cu-Co electrolyte [21]

Copper-Cobalt electrolyte	Concentrations
CuSO <sub>4</sub> .6H <sub>2</sub> O	6.99 g/L
Na <sub>2</sub> CO <sub>3</sub>	2 g/L
CoCl <sub>2</sub> .6H <sub>2</sub> O	1.09 g/L
KNaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> .4H <sub>2</sub> O (Rochelle Salt)	22.57 g/L
NaOH	4.5 g/L
Formaldehyde 37%	6 ml/L

All powders of the antecedent were broken down in DI water under attractive stirrer for 5 minutes. Formaldehyde is added to the arrangement subsequent to ensuring dissolving every one of the powders in the arrangement. When the formaldehyde was added, Actuated CNTs were placed in the electroless shower under attractive stirrer for 10 minutes and the response began to happen on the reactant surface of Pd-covered Cnt's. Air bubbles began to emerge from the arrangement once the CNTs were added. This occurred as an indication of dissolving hydrogen from the outer layer of the palladium as well as the oxidation of formaldehyde that produces hydrogen. The arrangement was then put under attractive mixing for an additional 30 minutes. When the air bubbles halted, it gave a decent sign that copper has totally covered the whole impetus surface. For this situation the copper surface turned into an auto-impetus and the arrangement became a brilliant shade of brown demonstrating the inclusion of CNTs by copper. After the blending is finished, the copper covered CNT's begun to collect in the lower part of the measuring utencil because of their expanded thickness. The arrangement was then filtered. The shade of the filtered arrangement was observed in the start of the filtration cycle and being light pink showing the utilization of all the copper particles in the arrangement before the filtration was

accounted for. Figure 2 shows the shade of the acquired copper covered CNTs powder.



Figure 2: Filtered copper coated CNT's of a brown color

The copper coated CNTs were characterized using scanning electron microscopy (SEM) analysis using (JEOL-JSM 6510 A) at the Materials Laboratory of Mechanical Engineering Udayana University.

### 2.2.4 Al-MWCNTs Composite Manufacturing Process

Materials for composites, aluminum and multiwall carbon nanotubes with varying compositions (0% ; 2%; 4%; 6%; 8% and 10% by weight MWCNTs) were included in the smelting kowi. Heated to a temperature of 700 °C with a time of 20 minutes and a stirrer speed of 200 rpm. The composite melt is poured into a cylindrical metal (steel) mold at room temperature. The equipment used in this stage is shown in Figure 3.

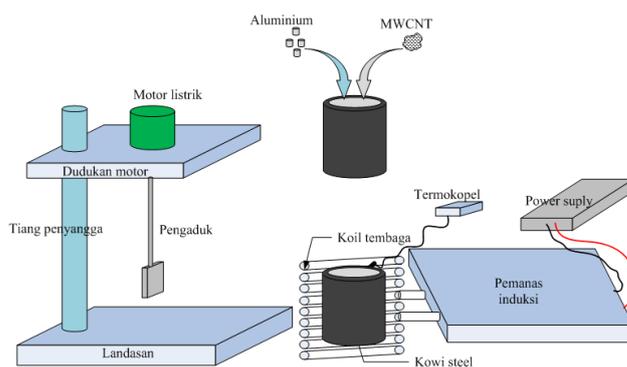


Figure 3: Design of equipment systems for composites fabrication

### 2.2.5 Density of Al-Cu/MWCNTs Composites

Density measurement refers to Birkeland [22]; ASTM C 134 - 95, and performed using Archimedes' principle. The measurement of the density of the Al-Cu/MWCNTs composite material is a test object resulting from the stir casting process. The procedure for measuring the density of the Al-Cu/MWCNTs composite material is carried out in the following steps:

- The sample was dried in an oven at 100°C with a drying time of 2 hours, then weighed its mass with a digital balance, called dry mass ( $m_s$ ).
- Weigh the mass of the sample along with the hanger (using a wire) in the water using a digital balance,  $m_g$ .
- Weigh the mass of the hanging wire using a digital balance,  $m_k$ .

By knowing these quantities, the density of the Al-Cu/MWCNTs composite material can be determined using the equation [22],

$$\rho = \frac{m_s}{m_s - (m_g - m_k)} \times \rho_{H_2O} \quad (1)$$

with,

$\rho$  = bulk density (gram/cm<sup>3</sup>)

$m_s$  = mass of the sample after drying in the oven (grams)

$m_g$  = mass of sample suspended in water (grams)

$m_k$  = mass of sample hanging wire (grams)

$\rho_{H_2O}$  = density of water = 1 gram/cm<sup>3</sup>

### 2.2.6 Porosity of Al-Cu/MWCNTs Composites

Measuring the porosity of Al-Cu/MWCNTs composite materials, refers to Birkeland [22]; ASTM C 373 - 88. The procedure for measuring the porosity of the Al-Cu/MWCNTs composite material is carried out in the following steps:

- The samples were dried in an oven at a temperature of 100 °C with a drying time of 2 hours then weighed the mass with a digital balance,  $m_s$ .
- The sample is boiled in water at 110 °C, until the mass of the object is in a state of saturation (saturated), then wipe the surface with a cloth, and weigh the mass using a digital balance,  $m_b$ .
- Weigh the mass of the sample along with the hanger (using a wire) in the water using a digital balance,  $m_g$ .
- Weigh the mass of the hanging wire using a digital balance,  $m_k$ .

By knowing these quantities, the porosity of the Al-Cu/MWCNTs composite material can be determined using the equation [22],

$$\rho = \frac{m_b - m_s}{m_b - (m_g - m_k)} \times 100\% \quad (2)$$

with,

$\rho$  = bulk density (gram/cm<sup>3</sup>)

$m_s$  = mass of the sample after drying in the oven (grams)

$m_b$  = mass of the sample after soaking in water / saturated (grams)

$m_g$  = mass of sample suspended in water (grams)

$m_k$  = mass of sample hanging wire (grams)

### 2.2.7 Hardness of Al-Cu/MWCNTs Composite (Vickers Hardness Test)

The hardness of the Al-Cu/MWCNTs composite material was tested at the Metallurgical Laboratory of Mechanical Engineering, State University of Malang using a Microhardness Tester (ESEWAY, Model EW421AAT), and the test refers to the standard Dowling [23]; ASTM E 18 - 02. The hardness test procedure is as follows:

- The surface of the test object is first sanded using sandpaper starting from the roughest to the smoothest.
- Place the sample in the holder, the given load is 100 grams and the identification time / dwell time is 10 seconds.
- After pressing, observe the resulting indenter, such as a diamond (Figure 4) by adjusting the focus until the observed shape is quite clear.

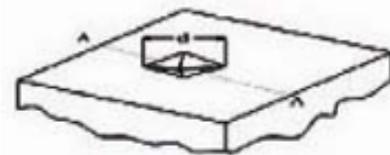


Figure 4: Vickers Hardness test results

- Measure the diagonal length of each pressing result and the hardness value of the tested sample can be read directly on the microhardness tester monitor, perform at least 3 repetitions for each sample tested.

The hardness value of the Al-Cu/MWCNTs composite material can also be calculated using the following equation [23].

$$VHN = \frac{2P}{d^2} \sin \frac{\alpha}{2} = 1,8564 \frac{P}{d^2} \quad (3)$$

with :

VHN = Vickers hardness value (kgf/mm<sup>2</sup>)

P = pressing load (kgf)

d = average diagonal length (mm)

$\alpha$  = angle between diamond faces (136°)

### 2.2.8 Thermal Conductivity

The value of the thermal conductivity of a material shows the rate of heat transfer flowing in a material. The thermal conductivity of most materials is a function of temperature, and increases slightly as the temperature increases, but the variation is small and often negligible. If the value of the thermal conductivity of a material is greater, the greater the heat flowing through the object. Therefore, a material with a large k value is a good heat conductor, whereas a material with a small k value is a poor conductor or an insulator [24]. In this study, for the thermal conductivity test, Linear Heat Conduction Devices (TD1002a) were used.



Figure 5: Linear Heat Conduction Experiment (TD1002a)

The working principle of the tool is that there is a heat source on the left side and a heat sink on the right side so that there is a fairly large (significant) temperature difference along the metal being tested. The heat source comes from an electric heater, the test object and its heater are all isolated. The test object consists of brass, copper, aluminum and stainless steel with a thickness of 20 mm and a diameter of 30 mm.

The energy that occurs in the heater is given by the equation:

$$W = V \times I \quad (4)$$

With ,

W = Electrical power (watts)

V = Voltage (volts)

I = Electric current (amperes)

Heat transfer that occurs:

$$\dot{q} = k \cdot A \cdot \frac{dT}{dx} \quad (5)$$

With ,

$\dot{q} = \frac{dQ}{dt}$  = heat transfer rate (Watts)

K = conduction heat transfer coefficient (Watt/m.K)

A = Cross-sectional area of metal test object (m<sup>2</sup>)

dT = temperature difference (K)

dx = distance between test points (T<sub>1</sub> and T<sub>2</sub>)

for this case W = q

### III. RESULTS AND DISCUSSIONS

#### 3.1 Products of Al – MWCNTs Composites

The aftereffects of the Al - MWCNT composite projecting cycle with different arrangements are displayed in Figure 6.



Figure 6: Product casting of Al – MWCNTs composites

Furthermore, the results of the Al - MWCNT composite casting are formed (lathe process) into a diameter of 30 mm and a thickness of 20 mm, for the process of testing physical properties, morphological characterization and thermal conductivity, Figure 7.

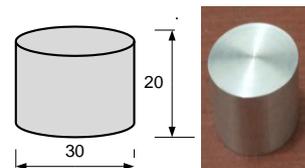


Figure 7: Al – MWCNTs composite casting product after turning

#### 3.2 Physical Properties of Al – MWCNTs Composites

Based on the results of calculations using equation (1) for the density test, equation (2) for the porosity test, as well as testing the hardness properties of Aluminum – Multiwall Carbon Nanotube composites, which were carried out in the Lab. Metallurgy Mechanical Engineering, Udayana University, obtained data as shown in table 2.

Table 2: Physical Test Data for Al – MWCNTs Composites

Composition specimen (% weight)	m <sub>s</sub> (gr)	m <sub>g</sub> (gr)	m <sub>k</sub> (gr)	m <sub>p</sub> (gr)	ρ <sub>H<sub>2</sub>O</sub> (gr/cm <sup>3</sup> )	ρ (gr/cm <sup>3</sup> )	P %	
0 MWCNTs	100 Al	38,83	25,65	1	39,5	1	2,738	4,512
2 MWCNTs	98 Al	37,92	25,15	1	39,3	1	2,754	9,109
4 MWCNTs	96 Al	37,78	24,65	1	38,9	1	2,674	7,344
6 MWCNTs	94 Al	37,15	24,13	1	38,7	1	2,650	9,955
8 MWCNTs	92 Al	36,95	23,65	1	38,5	1	2,584	9,779
10 MWCNTs	90 Al	36,78	23,27	1	38,3	1	2,535	9,482

##### 3.2.1 Effect of Reinforcing MWCNTs on Aluminum on Density

Based on Figure 8, it can be seen that with increasing MWCNTs content in Al – MWCNTs composites, the

composite density tends to decrease. The lowest composite density of 2.535 g/cm<sup>3</sup> occurred when the MWCNTs content was 10% by weight. Meanwhile, the highest composite density of 2.754 gr/cm<sup>3</sup> occurred when the MWCNTs content was 2% by weight.

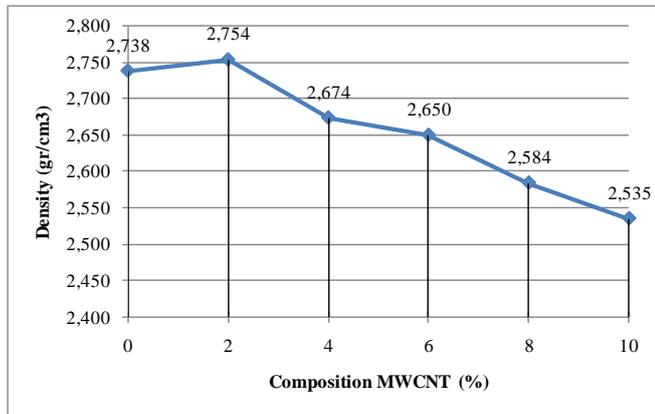


Figure 8: Tthe relationship between density and composition

### 3.2.2 Effect of Reinforcing MWCNTs on Aluminum on Porosity

Based on Figure 9, it can be seen that with increasing MWCNTs content in the Al – MWCNTs composite, the porosity of the composite tends to increase. The lowest composite porosity of 4.51% occurred when the MWCNTs content was 0% by weight. Meanwhile, the highest composite porosity of 9.96% occurred when the MWCNTs content was 6% by weight.

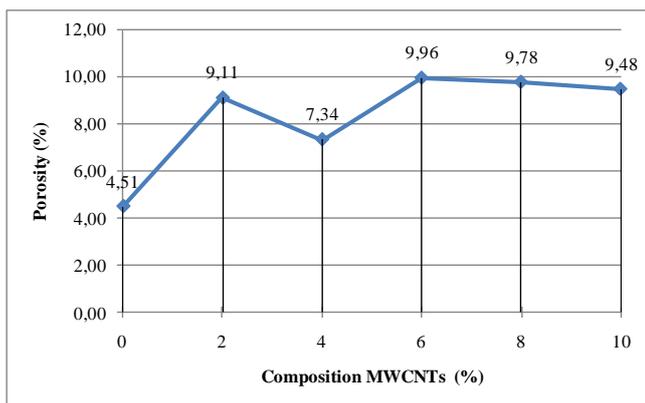


Figure 9: The relationship between porosity and composition

### 3.3 Microstructure of Al-MWCNTs Composites

In the example of the cast Al - Cu/MWCNTs composite, the Al grain morphology didn't change much contrasted with Al fine, as displayed in Figure 10. This is on the grounds that gravity projecting is applied during the arrangement of the composite, which helps the plasticizing of the powder to accomplish full thickness. Grain limits are seen all the more

plainly after continued drawing. In the unadulterated Al tests, little grain development (Figure 10a) and equiaxed grains were seen in all composites (Figure 10b and 10c).

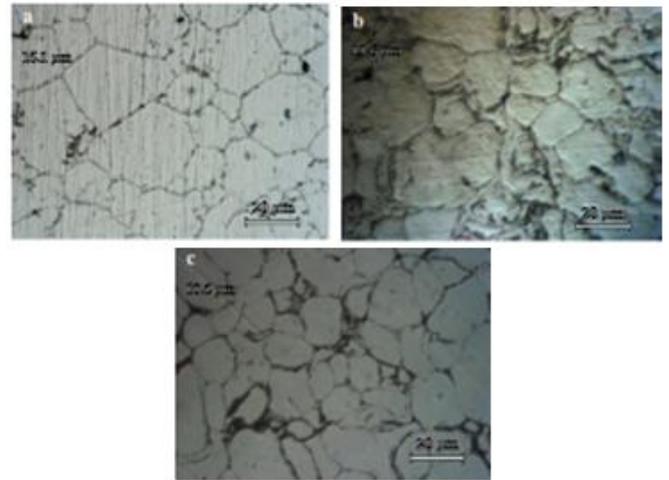


Figure 10: Microstructure image etched (a) pure Al, 1.0 wt.% (b) MWCNT/Al uncoated composite and (c) MWCNT/Al. Cu-coated composite

In the composite sample, the MWCNTs were homogeneously dispersed at the grain boundaries and within the Al particles. By comparing the grain size of the composite samples (Figure 10b and 10c) with the Al powder particles, it can be seen that the particle growth is very small. This is due to the embedding effect of MWCNTs which inhibits particle growth. It is important to note that the effect of Cu-coated MWCNTs increases more of the Al matrix binding interface. Therefore, small grain sizes were obtained in the Cu-coated MWCNTs/Al composites compared to the uncoated MWCNTs/Al composites, where little grain growth resulting in relatively larger grains was observed. Due to poor wettability in uncoated MWCNTs, the embedding of MWCNTs in Al particles was less during casting compared to Cu-coated MWCNTs/Al composites.

### 3.4 Effect of Reinforcing MWCNTs on Hardness

As previously mentioned, copper coated MWCNTs are added in varying percentages to the pure aluminum melt using casting techniques. The aim was to improve the wettability and dispersion between aluminum and MWCNTs which was reported to be very poor in a previous review [25]. The hardness of the sample was tested using a Vickers hardness tester. About 3 penetrations were carried out on a different area of each sample. The small variability of the Vickers hardness between the different indentations is indicative of the homogeneous distribution of Cu coated MWCNTs in the aluminum matrix. The results of the Vickers hardness number for various percentages of copper coated MWCNTs are presented in Table 3.

Table 3: Hardness test result data

Composition specimen (% weight)		Hardness (HV)
0 MWCNTs	100 Al	75
2 MWCNTs	98 Al	78,1
4 MWCNTs	96 Al	82,4
6 MWCNTs	94 Al	85,3
8 MWCNTs	92 Al	88,5
10 MWCNTs	90 Al	91,3

Based on Figure 11, it can be seen that with increasing MWCNTs content in Al – MWCNTs composites, the composite hardness tends to increase. The lowest composite hardness of 75 HV occurred when the MWCNTs content was 0% by weight. Meanwhile, the highest composite hardness of 91.3 HV occurred when the MWCNTs content was 10% by weight.

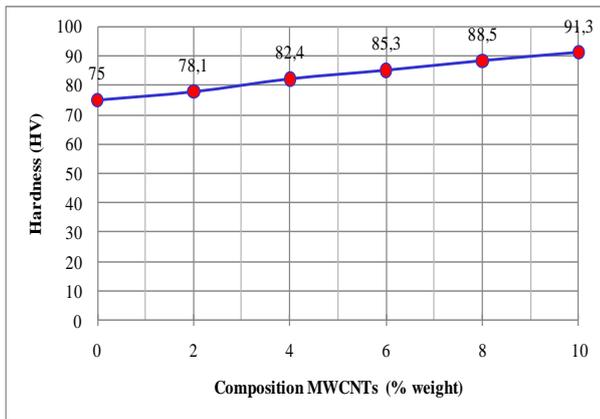


Figure 11: The relationship between hardness and composition

It was found that adding 2, 4, 6, 8 and 10% copper-coated MWCNTs to pure aluminum resulted in an increase in Vickers hardness of 4.13 ; 9.87 ; 13.73 ; 18.00 and 21.73% are significant especially that, for example, 2% copper-clad MWCNTs have less than 0.1% of MWCNTs. This confirms the potential of the process used in producing good quality cast composites from Al-Cu/MWCNTs. Efforts are underway to optimize the casting process and to fully investigate the mechanical behavior of the composite.

### 3.5 Thermal Conductivity Test Results

For the thermal conductivity test, Linear Heat Conduction Devices (TD1002a) were used which was carried out in the Lab. The Basic Phenomenon of Mechanical Engineering, Udayana University. The size of the test object is 30 mm in diameter and 20 mm thick, with a power input of 50 Watt. Based on the test results and the calculation of the thermal conductivity of the Aluminum – Multiwall Carbon Nanotube composite, the data is obtained as shown in table 4.

Table 4: Data from the heat conductivity test

Specimen Composition (% weight)		Thermal Conductivity (W/m.K)
0 MWCNTs	100 Al	252,42
2 MWCNTs	98 Al	318,47
4 MWCNTs	96 Al	330,27
6 MWCNTs	94 Al	350,49
8 MWCNTs	92 Al	442,32
10 MWCNTs	90 Al	294,88

Based on Figure 12, it can be seen that as the MWCNTs content increases in the Al-MWCNTs composite, the thermal conductivity of the Al-MWCNTs composite tends to increase. The lowest composite thermal conductivity of 252.42 W/m.K occurred when the MWCNTs content was 0% by weight. Meanwhile, the highest composite thermal conductivity of 442.32 W/m.K occurred when the MWCNTs content was 8% by weight.

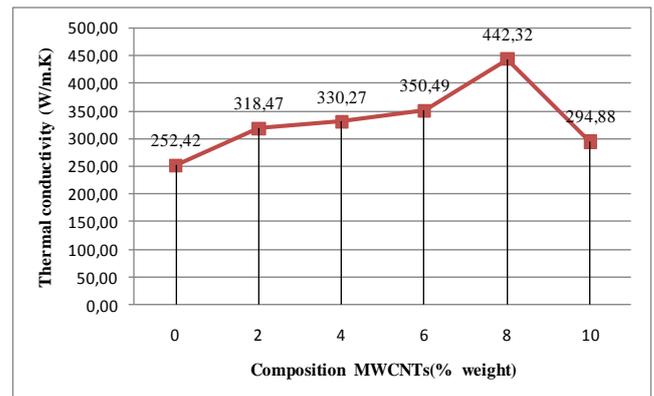


Figure 12: The relationship between thermal conductivity and composition

## IV. CONCLUSION

During the time spent making Al-MWCNTs composites with a mix projecting cycle, it tends to be reasoned that:

- The higher the MWCNTs content, the density of the Al-MWCNTs composite decreased, while the porosity of the Al-MWCNTs composite increased.
- The higher the MWCNTs content, the hardness and thermal conductivity of the Al-MWCNTs composite tend to increase.
- The distribution of MWCNT in the aluminum matrix was uneven and agglomeration of MWCNT occurred at several locations.
- Composites with the addition of <10 wt.% Cu/MWNTs have higher thermal conductivity than pure aluminum produced by the same liquid state processing.
- The Cu/MWNTs/Al composites showed a maximum thermal conductivity of 442.32 W/m/K at 8 wt.% Cu/MWNTs. The increase in thermal conductivity is

supported by the measured microhardness. The Cu/MWNTs/Al composites showed a maximum microhardness of 91.3 HV also at 10 wt.% Cu/MWNTs.

- f) The outcomes showed that the aluminum matrix composite supported with copper-covered multiwalled carbon nanotubes (Cu/MWNTs) is an expected material for high thermal conductivity applications.

## ACKNOWLEDGEMENT

The analyst offers his thanks for the subsidizing help from the Bali State Polytechnic DIPA 2022, with the goal that this exploration can be finished appropriately and can distribute this paper.

## REFERENCES

- [1] Ashby, M.F., Brechet, Y.J.M., Cebon, D., & Salvo, L., "Selection strategies for materials and processes", *Materials and Design*, vol. 35, no. 1, pp. 51-67, 2004.
- [2] Ray, P.P., "Surface Mount Technology: Principles and Practice". 2nd ed. Massachusetts USA: Kluwer Academic. pp. 3-723, 2002.
- [3] Braithwaite, N., & Weaver, G., "Materials in action series: Electronic Materials", London: Butterworth Scientific Ltd. pp. 11-82, 1990.
- [4] Reddy, P. G., & Gupta, N., "Material Selection for Microelectronic Heat Sink: An Application of the Ashby Approach", *Materials and Design*, vol. 31, no. 1, pp. 113-117, 2010.
- [5] Hartle, R. "How heat sink works. Available", <http://computer.howstuffworks.com/heat-sink.htm/printable>. Last accessed 27th January 2011.
- [6] Keller, K. P., "Cast heat sink design advantages", *IEEE intersociety conference on thermal phenomena*, vol. 1, no. 1, pp. 112-117, 1998.
- [7] Gallagher, Shearer, B., & Matijasevic, G., "Materials Selection Issues for High Operating Temperature (HOT) Electronic Packaging", *IEE*. vol. 1, no. 1, pp. 180-189, 1998.
- [8] Dogruoz, M. B., & Arik, M.. "On the conduction and convection heat transfer from lightweight advanced heat sinks", *IEEE transactions on components and packaging technologies*, vol. 1, no. 1, pp. 1521-1528, 2010.
- [9] Dogruoz, M.B., & Arik, M., "An investigation on the conduction and convection heat transfer from advanced heat sinks", *IEEE*. vol. 1, no. 1, pp. 367-372, 2008.
- [10] Kandasamy, R., Xiang-Qi, W., & Mujumdar, A.S., "Transient cooling of electronics using phase change material (PCM)-based heat sinks", *Applied Thermal Engineering*, vol. 28, no. 1, pp. 1024-1057, 2008.
- [11] Dai, H, "Carbon nanotubes: opportunities and challenges", *Surface Science*, vol. 500, Issues 1-3, pp. 218-241, 2002, [https://doi.org/10.1016/S0039-6028\(01\)01558-8](https://doi.org/10.1016/S0039-6028(01)01558-8)
- [12] Yoshida, Y., "High-temperature shrinkage of single-walled carbon nanotube bundles up to 1600 K", *Journal of Applied Physics*, vol. 87, no. 7, pp. 3338-3341, 2000.
- [13] Philip, G., Collins, M. S., Arnold & Avouris, P., "Engineering Carbon Nanotubes and Nanotube Circuits Using Electrical Breakdown", *Science*, vol. 292, issue 5517, pp. 706-709, 2001, doi : 10.1126/science.1058782
- [14] Berber, S., Kwon ,Y.K., & Tomanek, D., "Unusually high thermal conductivity of carbon nanotubes", *Phys Rev Lett*, vol. 84, pp. 4613-4616., 2000.
- [15] Kim, P., Shi, L., Majumdar, A., & McEuen, P.L, "Thermal transport measurements of individual multiwalled nanotubes", *Phys Rev Lett*, vol. 87, no. 21, pp. 5502., 2001.
- [16] Bakshi , S.R., Patel, R.R., & Agarwal, A., "Thermal conductivity of carbon nanotube reinforced aluminum composites: a multi-scale study using object oriented finite element method", *Comput Mater Sci*, vol.50, pp. 419-28, 2010
- [17] Yamanaka, S., Kadokura, H., Kawasaki, A., Sakamoto, H., Mekuchi, Y., Kuno, M., et al. "Fabrication and thermal evaluation of carbon nanotube/aluminium composite by spark plasma sintering method", *J Jpn Soc Powder Powder Metall*, vol. 53, no.12, pp. 965-970, 2006
- [18] Kim, C., Lim, B., Kim, B., Shim, U., Oh, S., Sung, B., et al., "Strengthening of copper matrix composites by nickel-coated single-walled carbon nanotube reinforcements". *Synth Met.*, vol.159, pp. 424-429, 2009.
- [19] Chu, K., Wu, Q.Y., Jia, C.C., Liang, X.B., Nie, J.H., Tian, W.H., et al. "Fabrication and effective thermal conductivity of multi-walled carbon nanotubes reinforced Cu matrix composites for heat sink applications", *Compos Sci Technol*, vol. 70, pp. 298-304, 2010.
- [20] Cohen, R. & Meek, R., "The chemistry of palladium—tin colloid sensitizing processes", *J Colloid Interface Sci.*, vol. 55, pp.156-162, 1976.
- [21] Shacham-Diamand, Y., Sverdlov, Y., Friedberg, S., & Yaverboim, A., "Electroless plating and printing technologies, in nanomaterials for 2D and 3D printing". In: S. Magdassi and A. Kamyshny (eds) Wiley-VCH

Verlag GmbH & Co. KGaA, Weinheim, Germany. 2017, <https://doi.org/10.1002/9783527685790.ch3>

- [22] Birkeland, P.W., "Soil And Geomorphology", Oxford, University Press New York, 1984.
- [23] Dowling, N., "Mechanical Behavior of Materials: Engineering Methods for Deformation, Fracture, and Fatigue", Prince hall, 1999.
- [24] Garnier, V., Fantozzi, G., Nguyen, D., Dubois, J. & Thollet, G., "Influence of SiC whisker Morphology and Nature of SiC / Al<sub>2</sub>O<sub>3</sub> Interface on Thermo Mechanical Properties of SiC Reinforced Al<sub>2</sub>O<sub>3</sub> Composites", Journal of the European Ceramic Society, vol. 25, issues. 15, pp. 3485-3493. 2005. doi : 10.1016/j.jeurceramsoc.2004.09.026
- [25] Agarwal, A., Bakshi, S.R., and Lahiri, D., "Processing techniques: Carbon nanotubes reinforced metal matrix composites", CRC Press-Taylor & Francis, Boca Raton, Florida, pp. 30–33, 2011.

#### AUTHORS BIOGRAPHY



**I Dewa Made Pancarana**, lecturer at Department of Mechanical Engineering, Bali State Polytechnic, Jimbaran, Bali, Indonesia.

The areas of interest that are in demand are manufacturing process, manufacturing technology, materials science, product design, composite materials, and several topics related to material characterization.



**I Nyoman Budiartana**, lecturer at Department of Mechanical Engineering, Bali State Polytechnic, Jimbaran, Bali, Indonesia.

The areas of interest that are in demand are manufacturing materials, material science, workshop technology, composite materials, and several topics related to material processing.

#### Citation of this Article:

I Dewa Made Pancarana, I Nyoman Budiartana, "Experimental Study of Thermal Properties of Aluminum Matrix Composites Inserted Multiwalled Carbon Nanotubes for Heat Sink Applications" Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 6, Issue 9, pp 100-108, September 2022. Article DOI <https://doi.org/10.47001/IRJIET/2022.609016>

\*\*\*\*\*